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LETTERS PATENT

SYSTEM AND METHOD FOR EFFICIENT ANALYSIS OF TRANSMISSION LINES

Inventors:

ALINA DEUTSCH

PETER FELDMANN

ALBERT E. RUEHLI

HOWARD HAROLD SMITH

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ANALYSIS OF TRANSMISSION LINES

BACKGROUND OF THE INVENTION

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1. Field of the Invention

The present invention relates to electrical circuit analysis, and more particularly to analysis of circuits, which involve transmission lines.

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2. Description of the Related Art

Electrical circuits with transmission lines are analyzed using circuits and numerical techniques to ensure proper functioning of the circuits. Examples of such

15 circuits include power distribution systems, which need to be analyzed for stability and other properties. The coupling and coupled signals between multiple lines is an important aspect of these power distribution systems.

Another example includes the analysis of circuits on

20 microprocessor chips where a bus with hundreds of wires is to be analyzed to determine whether the wire to wire coupling is excessive.

Similar issues occur in electronic circuitry where

noise coupled between transmission lines needs to be understood and minimized. Such issues occur in, e.g. instrumentation and/or computer circuitry in racks or cabinets.

5   The prior art uses multiple wire transmission line analysis techniques. Such techniques are described, for example, in the book by Clayton Paul, *Analysis of Multiconductor Transmission Lines*, Wiley, 1994, Chapter 5. Chapter 5 also includes the method of characteristics,
10   which are used to make models for multi-conductor transmission lines. These techniques are suitable for the analysis of models with a few lines; however, the complexity increases rapidly as the number of lines increases.

15   Some simplified techniques have been used to approximate the solution for many transmission lines with neighbor-to-neighbor wire coupling only. These approaches are suitable where reduced accuracy is acceptable to gain speed.

20   The prior art is limited in the number of coupled lines or wired they can analyze simultaneously. The complexity of the coupling calculation is increases rapidly as the number of lines increases, and the accuracy of the

results decreases with the increasing number of lines.

Hence, the prior art is unable to handle a large number of

lines due to excessive computation time and the results

become questionable. Some prior art techniques ignore the

5   couplings for more than two lines to speed up the process.

Some techniques are based on having only linear

circuits to speed up the calculation process. These

approaches are therefore unsuitable for handling even

typical transmission line circuits, which include

10   surrounding nonlinear drivers and receivers.

Therefore, a need exists for an improved system and method

for analyzing the coupling effects of transmission lines in

electrical circuits to assure the proper function of the

circuits. A further needed exists for a method and system

15   for analyzing these effects timely and accurately.

SUMMARY OF THE INVENTION

A system and method for analyzing a circuit with

transmission lines includes determining which sources

20   influence each of a plurality of transmission lines, based

on coupling factors. Transmission line parameters are

computed based on the sources, which influence each

transmission line. A transient or frequency response is

analyzed for each transmission line by segmenting each line to perform an analysis on that line. The step of analyzing is repeated using waveforms determined in a previous iteration until convergence to a resultant waveform has

5   occurred.

A computer system for analyzing one or more electrical circuits, the electrical circuits having two or more coupled lines, one of the lines being a victim line and one or more of the lines being an aggressor line includes one

10   or more circuit models and a transmission analysis process that selects one or more of the aggressor lines, being selected aggressor lines, and one or more rejected aggressor lines. The selected aggressor lines have a coupling factor with the victim line that is above a

15   coupling threshold. A solver process is includes that performs a nonlinear circuit analysis on the circuit model using the victim line and the selected aggressor lines but not the rejected aggressor lines.

The victim line may be adjacent to one or more of the

20   selected aggressors. The transmission analysis process may include the steps of determining a propagated signal for each of the selected aggressor lines; monitoring a coupling of the propagated signal on a first victim for each of the

selected aggressor lines; monitoring a coupling of the

victim couple signal on one or more second victims;

. comparing the victim couple signal to a previous victim

couples signal on the respective victim; and repeating the

5   steps until the comparison meets a comparison criteria.

These and other objects, features and advantages of

the present invention will become apparent from the

following detailed description of illustrative embodiments

thereof, which is to be read in connection with the

10   accompanying drawings.

BRIEF DESCRIPTION OF DRAWINGS

The invention will be described in detail in the

following description of preferred embodiments with

15   reference to the following figures wherein:

FIG. 1 is a block diagram of showing a system in

accordance with one embodiment of the present invention;

FIG. 2 is a block/flow diagram showing a system/method

for transmission line analysis using a transverse waveform

20   relaxation process in accordance with an illustrative

embodiment of the present invention;

FIG. 3 depicts an illustrative geometry for a multiple

transmission lines to be analyzed in accordance with the

present invention;

FIG. 4 is a block/flow diagram showing a system/method for scheduling/ordering computation of subcircuits in accordance with one embodiment of the present invention;

FIG. 5 is an illustrative graph showing convergence of waveforms within two iterations using the present invention; and

FIG. 6 is a schematic diagram showing coupling models for transverse coupling between multiple transmission lines in accordance with one aspect of the present invention.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

The present invention provides systems and methods for analyzing electrical circuits with transmission lines. In particular, the present invention provides ways for accounting for noise and other coupled effects from multiple neighboring lines and from the surroundings.

One embodiment of the present invention in includes a system and method for analyzing one or more electrical circuits where the electrical circuits have two or more coupled lines. One or more of the lines may be referred to as victim lines and one or more of the other lines may be referred to as an aggressor line or lines. The system provides one or more circuit models and a transmission

analysis process that selects one or more of the aggressor

lines (selected aggressor lines) and one or more rejected

aggressor lines. The selected aggressor lines include a

coupling factor with victim lines that have a value above a

5   coupling threshold. A solver process performs a non-linear

circuit analysis on the circuit model using the victim line

and the selected aggressor lines but not the rejected

aggressor lines. In this way, the analysis provides an

electrical response that considers all surrounding

10   influences on a given transmission line. This and other

embodiments will be described in greater detail herein.

It should be understood that the elements shown in the

FIGS. may be implemented in various forms of hardware,

software or combinations thereof. Preferably, these elements

15   are implemented in software on one or more appropriately

programmed general-purpose digital computers having a

processor and memory and input/output interfaces.

Referring now in detail to the figures in which like

numerals represent the same or similar elements and

20   initially to FIG. 1, an exemplary system 10 is shown to

illustrate one embodiment of the present invention. System

10 preferably includes a computer 12, which may be a

personal computer or a mainframe. Computer 12 includes any

interface devices known in the art. Computer 12 may

25   include a plurality of modules or software packages that

may be resident in the system or coupled thereto via a
network or the like. For example, computer 12 may be
provided access to electronic design automation (EDA)
libraries or other circuit databases 14, which include

5   electrical circuits or integrated circuit chip designs.

A module 16 may include one more programs or
subroutines for carrying out methods in accordance with the
present invention. Module 16 may include transmission line
analysis programs, including a solver 17 or code to

10   determine coupling factors, perform sliding calculations,
update coupling models and perform transient analysis,
among other things as will be described in greater detail
herein below. Module 16 may be incorporated into other
programming packages, such as full-blown circuit analysis

15   systems or programs.

A computer aided design (CAD) module or program 18 may
be include to import designs or design information to the
system 10 to provide the appropriate circuit analysis. CAD
schematics and or EDA data from database 14 may be employed

20   as inputs to module 16 to analyze components of a design,
and preferably transmission lines in the design.

Referring to FIG. 2, a block/flow diagram depicts a
program/method for implementing module 16 in accordance

with one embodiment of the present invention. The

transmission line analysis process may be referred to as a

transverse waveform relaxation process. In circuit

designs, one or more transmission lines may be present. To

5   handle a plurality of coupled lines, the impact of each

neighboring transmission line needs to be considered.

The present invention addresses neighbor-to-neighbor

coupling early on in the process. This keeps the problem

sparse if the model includes a large number of coupled

10   transmission lines. Also, a coupling model of parameters,

which have to be computed at the same time, is limited to a

relatively small number. The model limits the number of

coupled sources needed to represent the couplings. Then,

each wire is individually analyzed as a subcircuit while

15   the coupled sources are taken into account, and the

waveforms between the last two iterations are compared to

check for convergence.

In block 202, coupling factors are determined for

transmission lines in a given design. Coupling factors are

20   determined by calculating the influence of neighboring

lines on a given line. In one embodiment, an inductance

coupling factor (cf) may be calculated as:

$$cf = \frac{L_{12}}{\sqrt{L_{11}L_{22}}}$$ where L_{12} is the inductive influence of L_2

on L_1 (coupling term) and L_{11} is the inductance of line 1

and L_{22} is the inductance of line 2 (these may be referred

to as self terms). A similar coupling factor can be

5   calculated for resistance ($cf = \frac{R_{12}}{\sqrt{R_{11}R_{22}}}$) and capacitance

($cf = \frac{C_{12}}{\sqrt{C_{11}C_{22}}}$). Other coupling factors may be used and

preferably dimensionless variables. Also, default values,

e.g., 0.001, may be inserted into the program for coupling

factors to ensure a nonzero number exists in the case where

10   the coupling factor is not available or for other reasons.

The coupling factors are estimated first with

approximate computations. This leads to the knowledge of

how many transmission lines are to be included in each

segment of the calculation. The segments are computed in

15   an overlapping way such that all the interactions are taken

into account so that each line can be analyzed individually

taking into account the pertinent couplings for each line.

After calculating the coupling factors for

transmission lines in a design, the coupling factors are

20   compared to a threshold value(s), in block 204, to

determine if they will have an influence on neighboring

lines. For example, $L_{coupling} < L_{tolerance}$; $C_{coupling} < C_{tolerance}$;

and $R_{coupling} < R_{tolerance}$.

The tolerance or threshold is preferably set by a

designer but can also be calculated based on parameters or

criteria for a given design. For example, in sensitive

equipment, a smaller tolerance may be needed meaning

smaller influences should be considered in analyzing

transmission line parameters. Coupling factors that are

determined to be too small may be disregarded in future

calculations for a given segment. However, since many

circuits are dynamic and different portions of a circuit

may be operational at a different time, different time

frames may be investigated to ensure a complete solution.

For example, for a given line, coupling factors are

employed to determine the influence of other lines on the

line in question. Based on these estimates, the

calculations are segmented for each line to include the

most influential coupling effects.

In block 206, a sliding computation is performed to

calculate transmission line parameters (L, C and R). These

calculations are preferably based on geometric features.

The calculation of the per-unit line parameters L, R, and C

is preferably performed in a segmented way, e.g., one line

at a time, since the simultaneous calculation of these

matrix quantities is very expensive for more than a few

lines. Hence, each segmented calculation will include the

5   computation of the L, R, C parameters for a number of

lines. The number of steps needed to determine these

parameters is much smaller than the total number of lines

since the most influential lines are considered. This

simplifies the evaluation of the L, R, C parameters since

10   each sub-problem is much smaller than the large single

evaluation of each parameter.

For example, assuming 100 transmission lines, the

coupling evaluation determines that 5 lines should be

included near each line to accurately take the coupling

15   into account. So for the sliding calculation, the first 15

lines are evaluated simultaneously using, for example, a

standard field solver for L, R and C. This result can be

used for the first 10 lines in the transverse waveform

relaxation (WR) approach given herein. Then, in a next

20   sliding field calculation, the next L, R, C, are evaluated

for 15 lines from line 10 to line 25. Then, this

calculation can be used to evaluate the transverse WR for

lines 11 to 20, etc. Hence, the field calculation, is

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completed only on a subset of the lines which is much

faster since the compute time of the field solver

increases enormously with the number of lines considered.

In one embodiment, the characteristics of a circuit as

5   defined in a CAD schematic are employed to make these

sliding calculations.   The sliding calculations provide a

baseline for the transient analysis as will be described

hereinafter.

Based on the sliding computation, in block 208, a

10   coupling model or models are employed to reduce the circuit

characteristics into terms of voltage and/or current

sources with lumped elements (L, R, C)(See e.g., FIG. 6) or

alternately uses the method of characteristic models to

model the circuit.

15   In block 210, a transient of frequency domain analysis

of the transmission lines is performed preferably one wire

at a time. The transient/frequency analysis is based on a

transmission line response to surrounding circuits using

coupled sources to other coupled lines as provided by the

20   models set forth in block 208.

In a preferred embodiment, partitioning along the

coupling of the lines is performed. In other words, each

line is taken one at a time considering the most pertinent

coupling influences on that line. Alternately,

partitioning over the length of the line may be performed

as well or in addition to a calculation for the

partitioning of the coupling of the line.

5   In block 212, the transient analysis of block 210 is

repeated until convergence is achieved by comparing a

previous value of the waveforms determined by the transient

analysis from a previous iteration to the waveforms

determined in the present iteration. If convergence is

10   achieved the resultant waveforms have been determined and

are available in block 214. If convergence has not yet

been achieved, then the program returns to block 210 to

recalculate the waveforms.

          Referring to FIG. 3, example geometry for a multi-

15   transmission line geometry is illustratively shown.

Transmission lines 302 are numbered 1 to N in the depicted

section of a circuit 300. Lines 302 are marked with an A

to indicate that they are aggressor lines. These lines are

exited with some external circuitry. In contrast, the

20   lines which are marked with a V are victim lines which are

not excited with external sources.

          Using one method, e.g., set forth with reference to

FIG. 2, the subcircuits/lines of FIG. 3 are analyzed

starting at line 1, in sequence, until line N is reached.

This sequence is followed for each calculation in FIG. 2.

Then, the sequence is repeatedly followed go until

convergence in the transient/frequency analysis (e.g.,

5   blocks 210 and 212).

A more efficient method is based on signal flow. For

example, initially, all coupled waveform sources are set to

zero. Then, starting with the analysis of the circuits,

which include the aggressors (A) first, new coupled-source

10   quantities are available from the coupling model (block

206). Then, the nearest neighbors are analyzed since they

will include the largest signals next to the aggressors.

The process progresses through all the wires until all of

the wires have been visited. In each step/iteration, the

15   latest, updated waveforms are employed.

These methods are directly applicable to parallel

processing for circuit problems, which include transmission

lines. Each of the N transmission lines forms a separate

subsystem with a transverse decoupling scheme (e.g.,

20   portioning along coupling lines or effects). Further

partitioning is possible along the length of the line using

conventional techniques.

Partitioning or segmenting line by line (coupling)

leads to 2n subsystems which can be analyzed on separate

processors where the only information that needs to be

exchanged between processors is waveforms. Hence, an

enormous gain in speeding up the process by parallel

5   processing is achieved.

Referring to FIG. 4, a step for scheduling or

prioritizing an order for circuits to be analyzed is shown.

Block 400 may be performed prior to block 202 in FIG. 2 or

may be performed as needed at any point in the process.

10   The scheduling of the calculation may be performed based on

aggressor lines being calculated first and then nearest

neighbors to the aggressor lines moving outward therefrom.

Scheduling may include an algorithm for determining a best

order for analyzing the transmission lines of a circuit.

15   Referring to FIG. 5, a graph shows convergence of

waveforms within two iterations of applying the method of

the present invention. Input and output waveforms 501 and

503 are calculated theoretically. Upon application of the

present invention, a first iteration yields input and

20   output waveforms 505 and 507. Waveforms 505 and 507

overlap the calculated (exact) solution and cannot be seen

in FIG. 5 due to the overlap. In a second iteration,

waveforms show convergence after two iterations for the

input and output waveforms 509 and 511. The near and far

end coupled waveforms are shown to have converged.

The analysis of multiple transmission lines shows that

more than two neighboring wires should be included to get

5   an accurate coupled waveform for the case where 2 or more

neighboring active lines are present. It should be noted

that waveform iterations are needed to increase as a

function of the transmission line coupling factor. More

iterations are needed if the coupling factor is higher. In

10   accordance with the invention, even a coupling factor of

0.5, which is extremely high for practical transmission

lines, only needs 5 or less iterations to converge to a

result.

Referring to FIG. 6, exemplary coupling models 600 and

15   601 for the transverse coupling between multiple

transmission lines are illustratively shown. Several

different models can be used to represent the transverse

coupling between transmission lines. This is

schematically shown in FIG. 6.

20   Models 600 and 601 lumped circuit models with lumped

and/or distributed elements 603. The lumped circuit models

have sections where the coupling between the sections is

shown by dashed arrows 604. Depending on the circuit

model, sources 606 are voltage or current sources.

Alternately or additionally, method of characteristics

models represents another class of problems where the

coupling is performed mainly by a set of sources at the end

of the lines or sections. In the iteration process, the

sources 606 are updated as the results become available in

the solution process.

Having described preferred embodiments of a system and

method for efficient analysis of transmission lines (which

are intended to be illustrative and not limiting), it is

noted that modifications and variations can be made by

persons skilled in the art in light of the above teachings.

It is therefore to be understood that changes may be made

in the particular embodiments of the invention disclosed

which are within the scope and spirit of the invention as

outlined by the appended claims. Having thus described the

invention with the details and particularity required by

the patent laws, what is claimed and desired protected by

Letters Patent is set forth in the appended claims.